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SPECTRAL REFLECTANCE PROPERTIES OF WETLANDS PLANTS

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Abstract

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Wetlands occupy a unique position on the landscape. Being neither fully aquatic nor terrestrial, they are poorly understood from a standpoint of seasonal characterization and detection using spectral sensors. Wetlands ecotones and their associated plant communities offer a seasonally dynamic ecology which is governed primarily by fluctuations in local hydrologic regimes. Biogeochemical dynamics, caused by fluctuations in hydrology, work to manifest changes in plant physiology and provide a challenge for the spectral characterization and detection of wetlands. This paper presents information on the spectral reflectance characteristics of wetland plants and attempts to relate changes in spectral reflectance to the seasonal stresses experienced by wetlands plant communities.

1. INTRODUCTION

Numerous studies have documented the relationship between spectral and morphological changes in plants growing in a wide array of medium types and substrates (*Milton et al., 1991*). This research supports geobotany and agriculture with respect to vegetation growth stages and condition. Attempts to correlate changes in plant spectra and physiology due to uptake of pollutants have also been carried out (*Clark, 1982*). Most of these studies, however, have involved terrestrial plants grown in controlled environments to limit the effects of cation exchange, which could influence desired experimental results.

Wetlands plants differ greatly from terrestrial plants in response to stress. Depending on hydrologic regime, wetlands plants undergo biophysical changes during the growing season to cope with flooding and the resulting anaerobiosis. Anaerobic respiration requires a completely different energy requirement from plants than does aerobic respiration. The efficient production of biological energy is lost in the anaerobic pathway and, provided anaerobic conditions are extended throughout the growing season, this pathway can be lethal to plants not adapted to flooded conditions. For example, flood tolerance has been linked to the production and accumulation of non-toxic malate as a by-product of metabolism (Figure 1). Flood-intolerant plants also produce malate; however, malate is converted to pyruvate, which is further reduced to ethanol. Although ethanol is toxic to root tissues, *Mitsch and Gosselink, (1986)* suggest that ethanol diffuses out of the roots of flood-tolerant plants. Additionally, metals speciation and nutrient availability modified by the anaerobic environment place an extra burden on plants.

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The goal of this study was to test the hypothesis that the stress experienced by wetlands plants (due to seasonal flooding) can be characterized using ground-level spectral reflectance data in the .4 to .9 μ bandpass. This in turn would form the basis for developing a seasonal "wetland signature," therefore allowing data acquisition strategies to be developed for imaging spectrometers. In this experiment, stress is a function of the reduction-oxidation (REDOX) potential. REDOX potential describes the reducing condition of soils whereby

the availability of oxygen and cation exchange capacity is altered due to a positive or negative electric potential (recorded in millivolts) (Wetzel, 1983). In strongly reduced conditions such as flooded environments, the REDOX potential can fall to low levels (-200 mv) causing the transformation of metals and nutrients and rendering them unavailable for uptake by plants (Table 1). This serves to cause stress in plants (Mitsch & Gosselink, 1986).

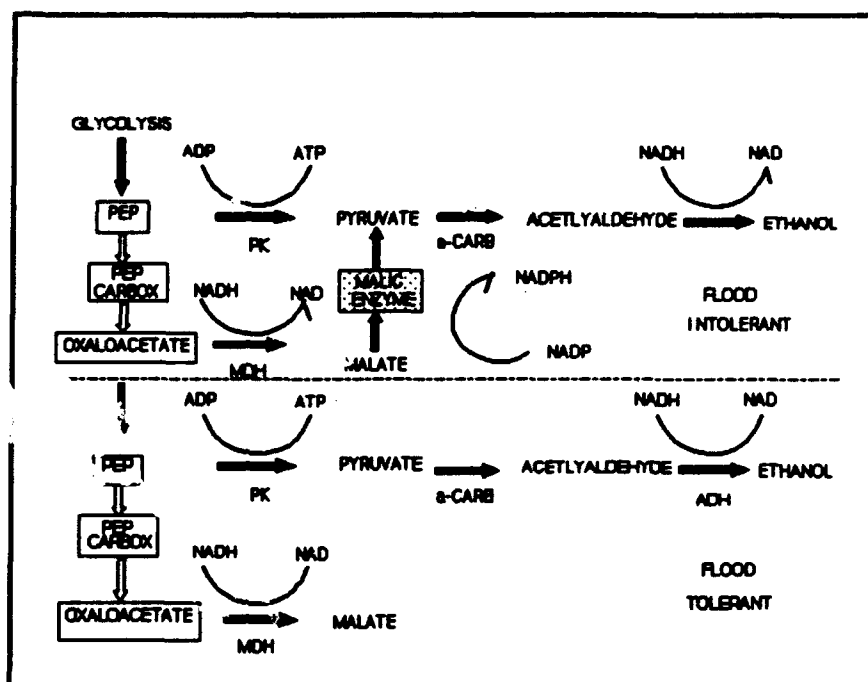


Figure 1. Metabolic pathways for flood intolerant and flood tolerant plants. (Adapted from Mitsch and Gosselink, 1986)

Table 1. Transformed Elements and REDOX Potentials

ELEMENT	Oxidized Form	Reduced Form	REDOX Potential
Nitrogen	Nitrate	Nitrous Oxide	220 mv
Manganese	Manganic	Manganous	200 mv
Iron	Ferric	Ferrous	200 mv
Sulfur	Sulfate	Sulfide	-75 to -150 mv
Carbon	Carbon Dioxide	Methane	-250 to -350 mv

Adapted from Mitsch & Gosselink, 1986.

2. METHODS

2.1 SITE SELECTION

Two wetland areas bordering the Rappahannock River in Virginia were selected for this study. These areas were colonized by the facultative (FAC) wetland species *Acer rubrum* (red maple). Red maple was selected owing to its tolerance to flooded environments and its status as a FAC wetland species. This categorization means that the species is found in wetlands 33% to 66% of the time. For this investigation, it was important to select two of the same species of wetland plants to ensure similar physiological responses to stress. The sites have their own distinct hydrological regime and are close to one another on gradients characterized by zones III and V along the stream terrace. Site 1, lying along a stream tributary (zone III), is "semi-permanently flooded" (Cowardin *et al.*, 1979) and subjected to standing water periodically throughout the growing season. Site 2 (zone V) is drier, "temporarily flooded" (Cowardin *et al.*, 1979), and not subject to total seasonal inundation. The soils of each site are mapped as Congaree loam and Wehadkee local hydric soil units.

2.2 REDOX AND SPECTRAL REFLECTANCE MEASUREMENTS

REDOX and spectral measurements were collected during the early part of the growing season for both sites on a weekly basis for three weeks. Other measurements such as water level, pH, specific conductivity, and dissolved oxygen were also collected. REDOX measurements were made using a Cole-Parmer pH meter with a platinum ORP probe. *In-situ* REDOX measurements were made on moist and inundated soils adjacent to the plant specimens. All measurements were averaged and recorded in millivolts (mv).

Spectral measurements were taken in the field from leaves excised from 25 trees sampled at random along a 30-meter transect. The tree stands averaged 13.4cm diameter breast height (DBH). As accessibility permitted, three leaf samples were obtained from different portions of the tree canopy to limit spectral anomalies between leaf samples occurring high or low in the canopy. Leaf spectra were obtained using an Analytical Spectral Devices (ASD) PS II field spectroradiometer (350 nm–1100 nm) with a 5 degree field-of-view (.0872 rad). This is approximately equal to a 8 cm diameter field-of-view at a 1 m sampling distance. Three spectra of each leaf sample were taken and then averaged to help improve signal-to-noise levels in the resulting spectral file. All measurements were taken as close to local (solar) noon time as possible. Procedures for obtaining spectra were followed according to those established by Satterwhite and Henley, 1991. All measurements were referenced to a Labsphere Spectralon reflectance standard. All targets and reflectance standards were leveled with a bubble level, and data were collected at a nadir viewing angle.

Raw spectral data files were processed using an existing software routine to convert all binary files into ASCII. The resulting spectral data sets were smoothed and reduced to 5 nm data using an interpolation program which applied a cubic spline algorithm.

3. RESULTS

3.1 SPECTRAL CHARACTERISTICS AND REDOX

Figure 2 is an example of the averaged spectral data and corresponding REDOX measurement taken from wet and dry site red maple specimens. In comparison to the dry site where REDOX

Spectral Reflectance and Redox Potentials

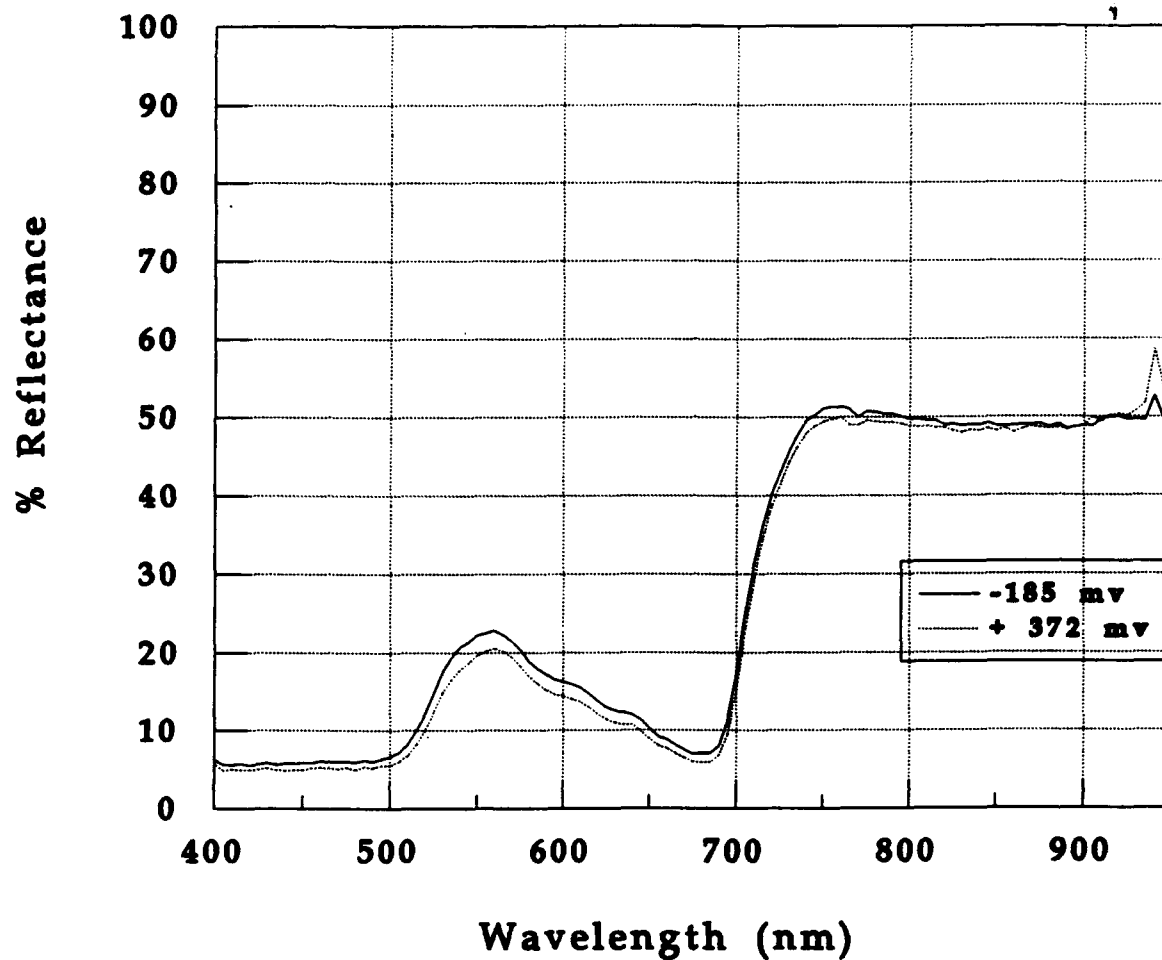


Figure 2. Spectral data averages and Redox potentials.

potentials averaged +372 mv, wet site REDOX potentials averaged -185 mv during the two-week period of saturation. Spectrally, chlorophyll reflectance in stressed red maples was slightly elevated at 560 nm. There was also an insignificant elevation in the chlorophyll absorption bands at 435 and 675 nm. Most notably, a displacement between the averaged spectral curves exists along the "red edge" boundary between 740 and 780 nm. This suggests that a red edge shift may exist for (FAC) wetlands plants stressed by prolonged flooding. The red edge shift is a theoretical spectral characteristic diagnostic of maturing, healthy green vegetation. It is described as the position of the chlorophyll absorption edge shifting toward longer wavelengths as plants mature (Collins, 1978, Campbell, 1987).

3.2 STATISTICAL EVALUATION OF RED EDGE INFLECTION POINTS

First derivative curves for the spectral samples were generated for the wet site and dry site red maples. Established methods (Salisbury et al. 1987; Milton et al. 1991; and Horler et al. 1980) were used to analyze the maxima of the first derivative spectra to characterize the inflection points associated with the red edge. The resulting first derivative curves illustrate a detectable red edge shift between the wet and dry specimens (Figure 3). A t-test (two-sample analysis) was employed to test the variability of the sample first derivatives between wet and dry site red maple specimens. Table 2 shows the descriptive statistics and Table 3 provides statistical results of the t-test for the first derivatives.

Table 2. Descriptive Statistics for Sample First Derivatives

Variable	DRY SITE (+372 mv)	WET SITE (-185 mv)
Sample Size	25	25
Average	715.4nm	706.5nm
Median	715nm	707nm
Mode	719nm	708nm
Mean	715.3nm	706.4nm
Variance	9.75	2.75
Standard Deviation	3.12	1.66
Standard Error	0.62	0.33

4. DISCUSSION

The results computed for the red edge first derivative maxima indicate that a statistically significant difference exists between the spectral characteristics of red maples on wet and dry sites having different REDOX potentials. Since plant chemical assays were not performed, it can only be speculated that the transformation of available plant nutrients under severely reduced conditions contributed to the stress of the wet site specimens. However, the rejection of the null hypothesis confirms the statistical significance of the variability between wet and dry site specimens and warrants

First Derivatives for Reflectance Spectra

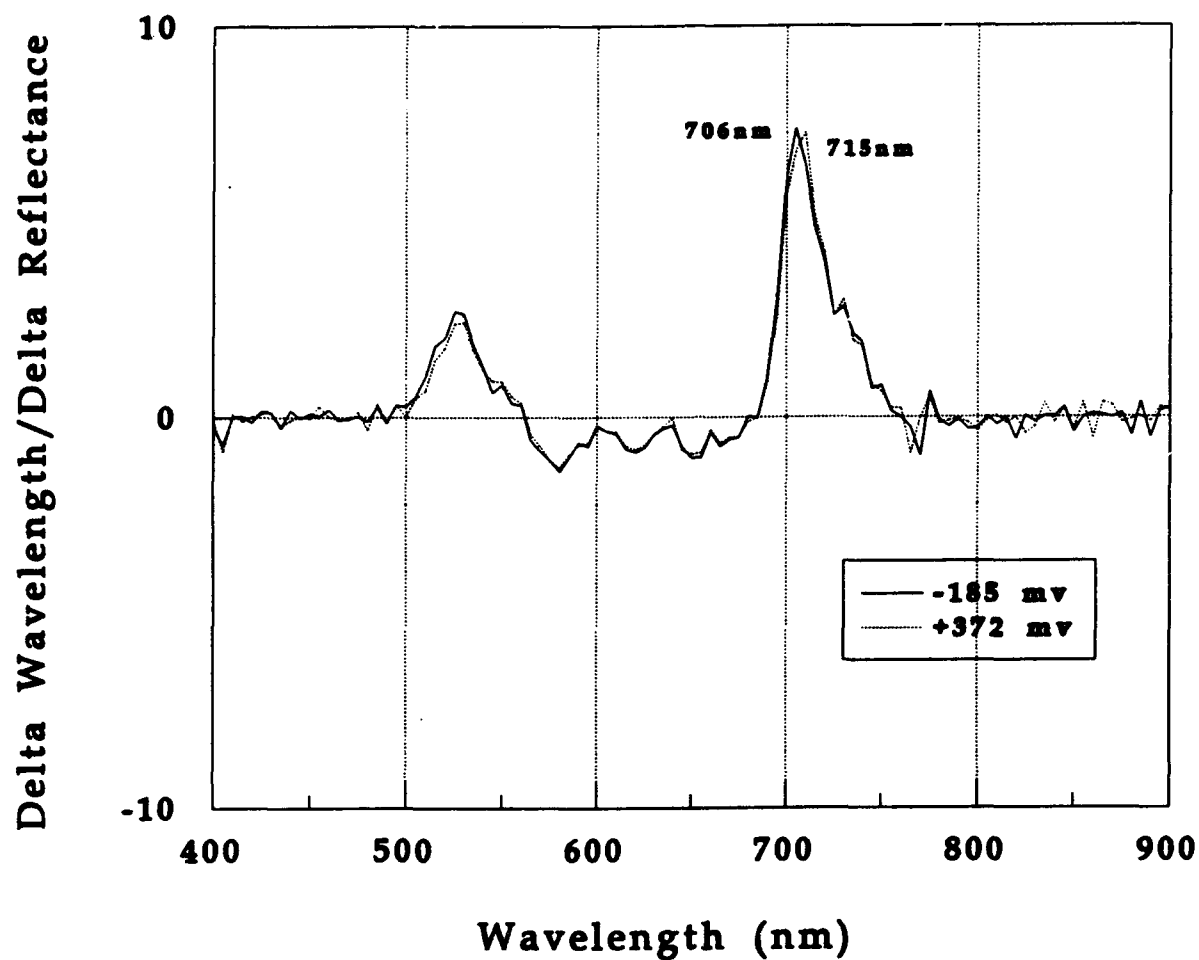


Figure 3. First derivatives for spectral curves and associated redox potentials.

further investigation. The differences in maxima characterizing the red edge is consistent with other investigations involving nutrient and metals stress in plants (Milton *et al.*, 1987 & 1991). The difference here is that the stress is not anthropogenic, but due to natural phenomena.

Table 3. t-Test Results for First Derivative Inflection Points

SAMPLE STATISTICS	DRY SITE (+372 nm)	WET SITE (-185 nm)
Number of Observations	25	25
Average	715.4nm	706.59nm
Variance	9.75	2.75
Std. Deviation	3.12	1.66
Median	715nm	707nm
Difference between Means = 8.84 Conf. Interval for Diff. in Means: 95% (Equal Var.) Sample 1-Sample 2 -10.2624 -7.41756 48 D.F. (Unequal Var.) Sample 1-Sample 2 -10.374 -7.40596 56.8 D.F.		
Hypothesis Test (H0) at Alpha = 0.05	Computed t Statistic = -11.49	Reject H0

The results of this study suggest that wetlands occupied by monotypic stands of (FAC) vegetation, subjected to prolonged flooding, can be stressed to the degree that subtle changes can be detected with spectroradiometers. If this is the case, a strategy may exist for mapping wetlands that are cloaked within stands of characteristically upland and FAC plant species. Ecotypic and adaptive variations within plant species are well documented and are ecologically significant (Brewer, 1979). Golet and Lowry (1987) documented the biophysical differences in the obligate species *Chamaecyparis thyoides* (Atlantic White Cedar) on six different sites in Rhode Island having six different hydrological regimes. Most of the variations between the sites occurred as a function of flooding, pH, tree crown cover, and stand density. Although spectral measurements and REDOX potentials were not considered, wide variations existed between the biophysical characteristics of the trees. Lowry (1984) also discovered growth variations among red maples on seven hydrologically distinct sites.

Although recordable with field and laboratory instruments, the detection of this phenomenon with imaging spectrometers may only be possible if the spatial and temporal variability of wetlands plants is observed long enough to characterize the specific stress signatures. In the case of facultative plants subjected to prolonged periods of flooding, the gap between the inflection maxima may widen to afford use of broader band sensors.

Clearly, a better understanding of the spectral behavior of wetlands plants is needed. These dynamic ecosystems are adapted to extreme and severe stresses which disrupt and prove fatal to flood-intolerant, upland plants. Furthermore, the spectral characterization of plants translates into observing a facet of the energy budget of an ecosystem. Changes in the way energy is transferred by wetland plants on a seasonal basis could provide a powerful diagnostic tool in managing wetland (and terrestrial) ecosystems.

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